Hydrologic Modeling of Coal Lands

May · 1979

A Cooperative Effort of the:
Bureau of Land Management &
Water Resources Division of the
United States Geological Survey

FOREWORD

During December 12-14, 1978, the Bureau of Land Management and the Central Region of the Water Resources Division, U.S. Geological Survey, convened in Billings, Montana, a workshop of hydrologists from both agencies to review the hydrologic modeling effort of the EMRIA program and to prepare a report for BLM management on the objectives, status, and future direction of the modeling effort.

This report hopefully answers all the questions management might have about the modeling effort. The report is aimed primarily at the field hydrologist in a BLM district or resource area involved with coal development activities. However, it has purposely been written at a level so as to be useful to the non-hydrologist as well. An Executive Summary has been included for the land manager and/or staff supervisor.

May, 1979

Bruce P. Van Haveren
Denver Service Center
Bureau of Land Management
Lakewood, Colorado

George H. Leavesley
Water Resources Division
U.S. Geological Survey
Lakewood, Colorado

Attendees at the workshop included the following persons:

Larry Cary	USGS-Billings
Bob Hejl	USGS-Albuquerque
Doug Emerson	USGS-Bismarck
Steve Playton	USGS-Oklahoma City
George Leavesley	USGS-Denver
Gregg Lusby	USGS-Denver
Bob Lichty	USGS-Denver
Dick Hadley	USGS-Denver
Larry Shiao	USGS-Denver
Celso Puente	USGS-Tuscaloosa
Mike Whittington	BLM-Billings
Dick McQuisten	BLM-Cheyenne
Boyd Christensen	BLM-Salt Lake City
Herb Garn	BLM-Sante Fe
Lee Koss	BLM-Tuscaloosa
Collis Lovely	BLM-Phoenix
Pat Green	BLM-Denver
Bruce Van Haveren	BLM-Denver
Ed Burroughs	US Forest Service-Bozeman
Rick Patten	US Forest Service-Orofino, Idaho

EXECUTIVE SUMMARY

Much of the concern over Federal coal development is centered around water resource impacts. The Surface Mining Control and Reclamation Act of 1977 stressed that before mining could occur, there must be assurance that the hydrologic balance of the mined-area could be returned to pre-mining conditions.

Six of the twenty-four departmental unsuitability criteria, namely (1) wetlands, (2) floodplains, (3) municipal watersheds, (4) national resource waters, (5) reclaimability, and (6) alluvial valley floors directly involve hydrology questions. In many situations, decisions about these criteria will be deferred to the activity planning stage for more detailed study. At that point, the hydrologist will be asked to answer some very site-specific hydrologic questions on coal development impacts. Usually, the necessary data to answer these questions will be lacking. Hydrologic models, however, provide a means of (1) estimating the hydrologic characteristics of small watersheds where actual data are not available, and (2) allow the hydrologist to impose hypothetical land-use activities on the hydrologic system for the purpose of predicting water resource impacts.

The BLM and USGS-WRD have cooperatively embarked on the development, testing and application of a small watershed hydrologic model that will provide BLM and USGS hydrologists the capability of predicting water resource impacts from coal development.

The model is a modular-design distributed-parameter hydrologic model that uses mathematical relationships to represent the hydrologic system. The USGS-WRD is responsible for developing and testing the model; BLM is responsible for interpreting the model outputs and for identifying and appraising the USGS-WRD of BLM's program needs.

Twenty study basins, used for development and testing of the model, have been established in the major coal regions involved in the EMRIA program. Two additional basins will be instrumented, one each in Utah and Wyoming. Approximately three to five years of data will be needed in order to calibrate and verify the model in unmined basins. The calibration process has begun already in Colorado and Alabama. Each basin was not only selected to represent the region it is in, but also selected for its high potential for being mined in the near future. Once mining occurs in the study basin, the model can be verified for its ability to predict hydrologic response during and after mining and through the reclamation phase.

Once the model has been calibrated and verified for unmined basins, it will be available for BLM use in problem solving on watersheds being considered for coal development. For basins where the model is to be applied, basic "driving variable" data will have to be collected or otherwise provided in order to run the model. The EMRIA program and the affected states are now looking at those data requirements for future funding needs.

Development of the major model components is nearly complete. We are now entering the model calibration and verification phase. Pre-mine calibration should be completed for some basins by the end of FY 80. Completion of the calibration and validation phase on mined basins will depend on the availability of data from those basins.

INTRODUCTION

The Energy Mineral Rehabilitation Inventory and Analysis (EMRIA) program of the BLM was initiated in 1975 to provide baseline soil, hydrology, and overburden information for the assessment of the rehabilitation potential of potential coal lease tracts within the surface-mineable Federal mineral estate. Early in the program, hydrology issues surfaced that represented major reclaimability problems for Federal coal lands in the U.S. Hydrology investigations were contracted to the U.S. Geological Survey, Water Resources Division (USGS-WRD), to assess these problems, These investigations now amount to roughly 3.1 million dollars annually. This concentration of funding in the water resources area represents the individual BLM state offices' interest in and concern for the magnitude and potential seriousness of water resources impacts that could result from large-scale leasing and mining of coal lands in the West.

The USGS-WRD has also been funded to look at potential impacts arising from large-scale coal mining. The WRD's interest in these studies is primarily the effects of coal development on groundwater systems and on river basins greater than approximately 50 mi^2.

In 1977, Congress passed the Surface Mining Control and Reclamation Act (Public Law 95-87), in response to interest from coal states and environmental groups. SMCRA specifically addressed hydrologic impacts of surface mining, stating that before a mine plan could be approved, the operation would have to show how the hydrologic balance of the mine area would be restored to pre-mine conditions. Furthermore, before a Federal land manager can issue a permit for a coal tract, he must be certain that the area proposed for mining is reclaimable, with "hydrologic balance" being one of the reclamation criteria. Hydrologic balance refers to the pre-mine hydrologic conditions, namely flow regimes, flood peaks and volumes, sediment yields, water quality, groundwater movement and recharge, and basin water balance relationships.

THE PROBLEM

By law and by administrative policy, the Federal land manager must incorporate into the leasing decision an assessment of hydrologic impacts that could result from mining. He also needs to write stipulations for a lease agreement in order to mitigate hydrologic impacts, when possible. Those impacts which cannot be mitigated must be evaluated in terms of what water resource values are lost and for how long. Management depends on staff specialist input for necessary data, interpretations, and recommendations relative to reclaimability questions.

Two points about reclaimability must be addressed. First, all lands subjected to surface mining can be reclaimed to the original pre-mining condition, given enough time and money. Therefore, questions and answers that address the reclamation potential issue must consider time and economics and, in general, what is "reasonable" in terms of reclamation measures. As one of the Secretary's unsuitability criteria, reclaimability is first addressed at the land-use planning stage (Resource Management Plan stage) at a map scale of approximately 1:125,000. This scale is much too small for the land manager to make site-specific decisions about hydrologic reclaimability (a lease tract may be comprised of 1 to 5 sections of land).

The second point to be made about reclaimability is that most, if not all, final decisions regarding reclaimability will actually be made at the coal activity planning stage at a map scale of approximately 1:24,000 or larger. This is the scale at which present EMRIA hydrology investigations are concentrated.

In addition to reclaimability, there are five other unsuitability criteria that involve hydrology considerations. In many situations, decisions about wetlands, floodplains, municipal watersheds, national resource waters, and alluvial valley floors will be deferred from the Resource Management Plan to the Coal Activity Plan for further resolution. Complete data needed to answer hydrologic questions about these criteria will nearly always be lacking.

The basic problem of developing sufficient information upon which to base reclaimability and related hydrologic decisions relates to time and money. Literally hundreds of potential coal lease tracts could be identified in the planning process. Present (and probably future) funding levels prevent us from studying all possible lease tracts. Furthermore, only one year has been allotted by the Secretary of the Interior for data collection between the lease tract delineation and tract ranking stages of Federal coal leasing. There is insufficient time to conduct traditional hydrologic studies, particularly in the arid western states where precipitation and runoff are highly variable from year to year. The BLM field hydrologist then needs a tool that will permit transfer of data from gaged basins to ungaged basins and that will also assist in making predictions about the hydrologic impacts of surface mining. The hydrologist will then be in a position to make interpretations and supportable recommendations to the land manager.

THE SOLUTION

Prediction of Surface Mining Impacts on the Water Resource

The basic objective in the EMRIA hydrology program is to adequately evaluate the hydrologic components of an area and predict their temporal and spatial variations with changes imposed by surface mining. The most accepted method of hydrologic component evaluation and prediction is the use of hydrologic or watershed models. To provide this modeling cap-

ability, the USGS-WRD and BLM initiated a cooperative model development and implementation program in 1976. The major objective of the cooperative USGS-BLM modeling program is to develop, test, and verify a hydrologic model package to predict the impacts of surface mining on the hydrology of basins in the coal regions. The model itself will provide:

(1) A means for estimating the hydrologic characteristics and processes of areas where basic hydrologic data are lacking.

(2) The capability of predicting hydrologic impacts from potential coal lease areas.

The Model

A model can be a conceptual (on paper), physical, or mathematical representation of a physical or natural system. In our case, we are representing the hydrologic cycle with mathematical relationships on a digital computer. The model package being developed by the USGS is a modular design program package. Each component of the hydrologic cycle will be defined by a model module (one or more subroutines). All modules will be compatible for linkage to each other and all will be maintained in a single computer system library. The library will also contain modules for parameter optimization, data handling, and model output analysis. Given a specific hydrologic problem, the hydrologist will be able to select a main program routine which calls the specific library modules that define his problem. Special requirements can be added by user-written modules or user modifications to library modules.

The distributed-parameter approach is used in model package development. This means that model components are designed around the concept of partitioning a basin into subunits on the basis of slope, aspect, altitude, vegetation type, soil type, and snow distribution. Partitioning attempts to account for temporal and spatial variations of basin physical and hydrologic characteristics, climatic variables, and system response. Each basin subunit is considered homogeneous with respect to its hydrologic response and is called a hydrologic response unit (HRU) (Figure 1). The sum of the responses of all HRU's, weighted on a subunit area basis, produces the total system response. This approach allows the hydrologist to evaluate impacts and processes at both the HRU and the total system levels.

The model structure is divided into four general areas of emphasis (components) with regard to the hydrologic cycle (Figure 2). These are the climatic, land phase, snow, and sediment components. Each component is composed of one or more program modules. Most of the components will be capable of operating in both a daily and an individual storm-event mode. No water quality component (except sediment) currently exists in the system and the ground-water component is initially being treated as a lumped-type reservoir system within the land-phase components. The modular structure of the model package will permit the addition and enhancement of these two components at a future date. As model development continues and more data become available, the initial model components also will be modified and improved to better predict the impacts of surface mining.

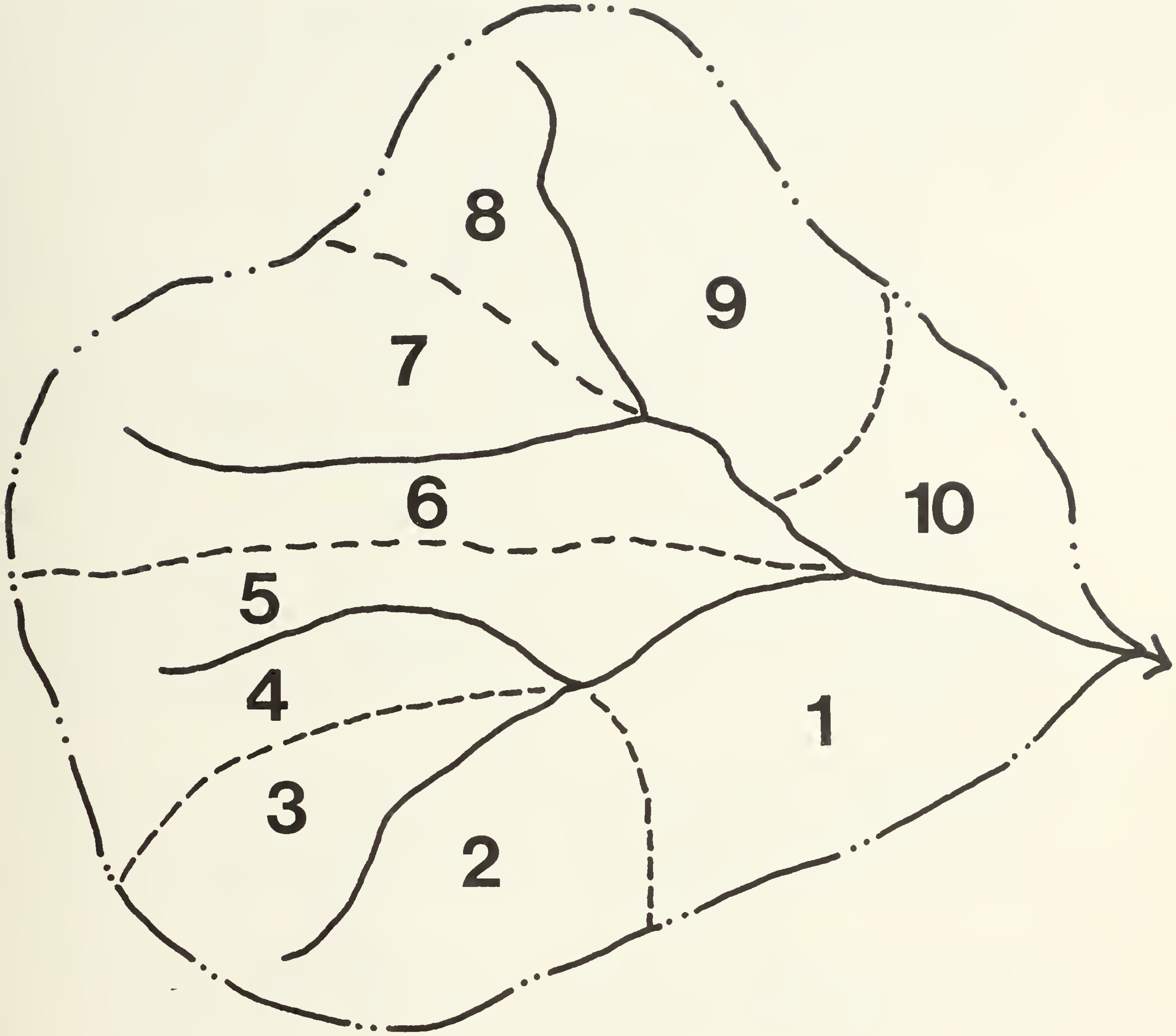

Figure 1. Example of a basin partitioned into hydrologic response units.

PRECIPITATION - RUNOFF MODELING SYSTEM

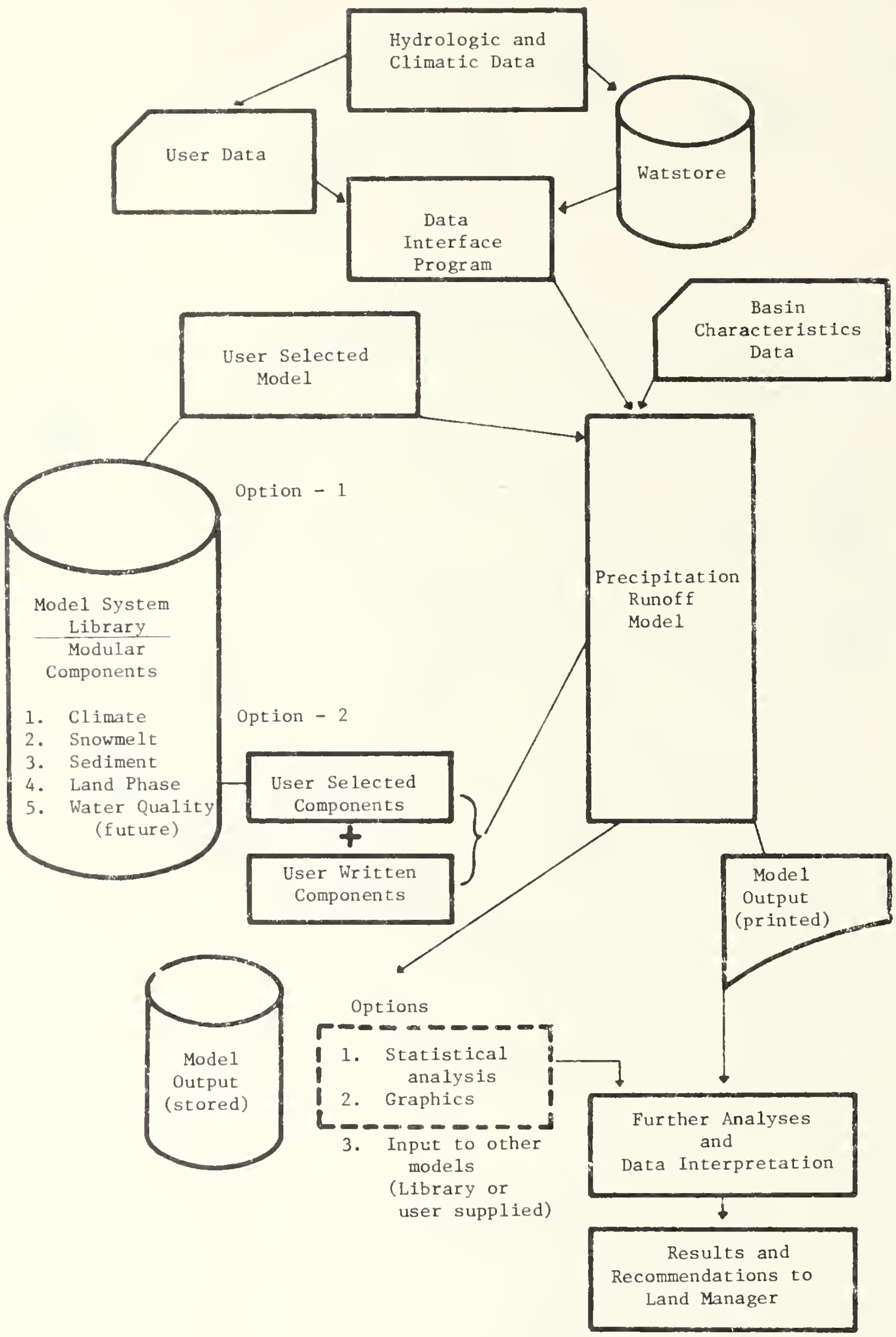

Figure 2.

Diagram of the modeling system showing all components and flow of information to the user group.

The climatic components accept input data from one or more climate stations and adjust these data to define the climate of each HRU. Variations in climate occur with changes in slope, aspect, altitude, vegetative cover, and time. To account for these variations, measured climatic data are corrected for each HRU using adjustment factors that are functions of the HRU's median altitude, slope, aspect, and vegetative cover. Adjustment factors must be developed by the hydrologist from regional climatic data.

The land phase components simulate the effects, responses, and interactions of the vegetation, soil, and geology of an HRU. This includes the processes of interception, infiltration, evapotranspiration, soil-water accounting, surface runoff, subsurface flow, and ground-water flow. To reproduce the physical reality of the hydrologic system as closely as possible, these processes are modeled using known physical laws or empirical relationships which have physical interpretation and measurable watershed characteristics.

The snow component simulates the initiation, accumulation, and depletion of a snowpack on each HRU. A snowpack is maintained and modified on both a water equivalent basis and as a dynamic heat reservoir. An energy balance in terms of caloric heat is computed daily for each HRU and the resulting gain or loss of heat energy is used to modify the existing snowpack conditions. A future addition of a coupled heat and moisture flow component will be used to simulate freezing and thawing of the soil mantle.

The sediment component will simulate the detachment of sediment from the soil surface, its transport to a channel, and its subsequent deposition in or transport from the basin. This component is currently in a research and development stage. Data collected from the study basins established in the coal regions will be used to test and verify this component.

The water quality component will simulate the pick-up and transport of specific quality constituents. While this component is not currently in the model system, it is felt that water quality modeling research being conducted in other project areas will be readily adaptable to the model system.

Studies on the surface water-ground water interactions, especially the interactions that occur in the unsaturated zone will be conducted so that the watershed model can be coupled with existing ground-water models. This is particularly important for ground-water recharge areas.

The initial model package is a combination of two USGS rainfall-runoff models and a snowmelt-runoff model, forming a library of compatible subroutines or modules. The modular concept will permit the application of this program package to a wide range of hydrologic problems. Model complexity will be a function of the user's problem and available data. Program module development is directed toward use in ungaged basins,

composed of various combinations of land use. Consequently, most modules are physical-process oriented and an attempt will be made to relate model parameters to measurable physical features of a basin. The modular flexibility will simplify the additions of new subroutines (e.g., water quality) and will permit rapid testing of new approaches to modeling various components of the hydrologic system.

Model Study Basins - Calibration and Verification

Twenty study basins have been selected in the coal regions involved in the EMRIA program (Figure 3). Selection criteria used are (1) that the basins be physically and hydrologically representative of the majority of basins to be mined in the region, (2) less than 50 mi^2 in size (preferably 5-10 mi^2), and (3) have a reasonable expectation of being mined within the next 3-5 years. If the region is composed of two or more distinctly different types of basins, then one or more basins of each type would be selected for study. It is expected that a total of 25-30 basins could ultimately be selected for study.

The major types of data collected on the study basins are hydrologic, climatic, and basin characteristics. The combination of these data will permit definition of the hydrologic system and provide information required for model development, testing, and verification. Hydrologic data include measurements of surface- and ground-water quantity and quality and the variation in these components with time. Soil-water data will be collected periodically.

Climatic data are collected using a network of precipitation gages, a complete weather station, and snowcourses where appropriate. Each study basin has an adequate precipitation gage network to measure the temporal and spatial variations of precipitation over the basin. Rainfall data are collected on a five-minute interval and snowfall data on a daily basis. A weather station will have been established for each basin or group of basins in a given coal region. All stations measure air temperature, relative humidity, solar radiation, and wind travel on an hourly basis. Additional sensors to measure soil temperature and soil water will be added to the climate stations in Montana and North Dakota to provide data on freezing and thawing of soils in those regions. The climatic data collection system is quite flexible and can be modified for collection of additional parameters which may be required for future model development or hydrologic analysis.

Data on basin characteristics are collected through the cooperative efforts of WRD District personnel, the Precipitation-Runoff Modeling Project, and the Public Lands Hydrology Project. Data are collected and analyzed to define basin soil properties, soil-water storage characteristics, infiltration characteristics, soil detachability, vegetation characteristics, and topography. A field-portable rainfall simulator is used to define the infiltration rates, overland flow, and sediment yields from various combinations of topography, soils, vegetation, and

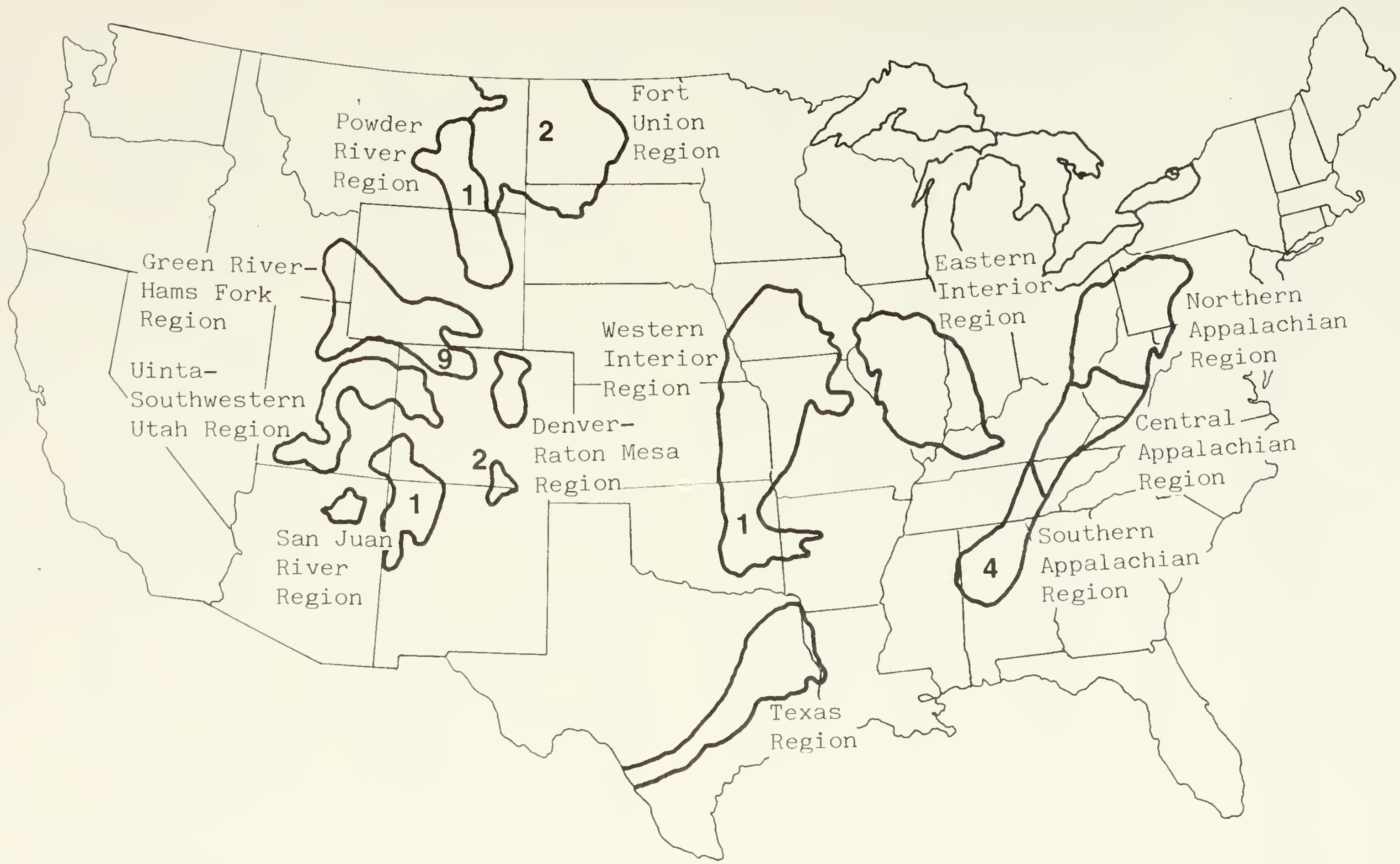

Figure 3.
COAL SUPPLY REGIONS OF THE UNITED STATES

(Numbers indicate the total number of study basins in the modeling effort for that coal region.)

land use. Rainfall simulator runs will also be made on active mine spoils if they are available in the region. Data from the rainfall simulator will be used in the development and improvement of runoff and sediment model subroutines. Concurrently, these data provide a measure of the usefulness of plot data in defining hydrologic characteristics of basin subunits in a distributed-parameter model.

What Kinds of Data Are Needed to Run the Model?

The climate data needed to run the model (also called driving variables) include data such as precipitation, solar radiation, air temperature, humidity, and wind. The model will also operate on precipitation and air temperature data only. However, prediction capabilities are improved with the addition of solar radiation, humidity, and wind data. Basin physical characteristics, soil and overburden characteristics, and vegetation data are also needed. The driving variable data must be provided for all ungaged basins to which the model will be applied. For some basins it may be possible to extrapolate the climate data from nearby stations having adequate records. Where this is not possible, climate stations must be established to create a new data base for the area of concern. Length of record needed will depend on how many years are needed to establish an adequate correlation with a longer term record, or to adequately characterize the area climate.

What are the Program Outputs?

When applied to watersheds having little or no hydrologic data, the model will define estimates of the hydrologic characteristics of the basin including the water balance of individual HRU's, streamflow hydrographs, flood peaks and volumes, sediment yields, water quality characteristics, soil-water relationships, and groundwater recharge. If a hypothetical mine plan is superimposed on the watershed, the model can be run to predict impacts of mining. These outputs can then be used by the hydrologist, who must then interpret the results for the land manager.

The accuracy of model predictions in gaged basins is measurable and will be determined using the calibration and verification phases of the program. The accuracy of model predictions in ungaged areas is not measurable. It will be a function of the transferability, from gaged to ungaged basins, of data from regional climate stations, hydrologic relationships developed from calibration watersheds, and information obtained from rainfall simulator plot studies. A theory of errors is being developed for the model to provide a means of making estimates of the probable error in model predictions for ungaged basins. This theory of errors will provide an estimate of the confidence limits on a model prediction given some estimate of the size of the errors in the model input data. Model accuracy will be discussed in terms of applying the model to an ungaged watershed with no impacts superimposed and, secondly, in terms of applying the model with mining superimposed on an ungaged watershed.

A user's manual will be developed by USGS in FY 80 for use by USGS and BLM hydrologists.

An annual progress report on the modeling effort will be prepared jointly by USGS and the EMRIA staff and submitted to the BLM State Offices, beginning at the end of FY 79.

How Does the Modeling effort Relate to the Bureau Planning System and Coal Leasing Program?

The model has been designed to evaluate hydrologic processes and predict hydrologic impacts at the coal activity planning stage. However, the model could be used to extend hydrologic knowledge to ungaged areas within a planning unit for URA purposes. The model could also be used to evaluate the technical feasibility of water resource management opportunities proposed in the Unit Resource Analysis, Step IV. At the Resource Management Plan stage, the model could be used to evaluate various alternatives of land use mixes and their consequent impacts on the water resource. The model will find its most important application during the tract delineation, evaluation, and ranking stages of coal activity planning. During site specific analysis of the delineated tracts, the model can be applied to predict impacts of mining and to design stipulations or mitigating measures related to hydrology.

The modeling program has spin-off benefits as well. Eventually, depending upon its sensitivity, the model could be used to evaluate impacts of any major proposed land-use action, whether it be grazing or timber harvest.

Responsibilities

The modeling program is a joint effort of the USGS-WRD and the BLM. Fiscal support is shared by the USGS-WRD Coal Hydrology Program and the BLM's EMRIA program. Technical development and testing of the model is the responsibility of the USGS-WRD. Application of the model to BLM needs and programs is the responsibility of the EMRIA Staff and the BLM State Offices involved with coal development. The BLM District and Resource Area hydrologists are the ultimate users of the model outputs. It is their responsibility to interpret the model outputs for the District Manager and make subsequent water resource recommendations to him. The BLM field hydrologists and local USGS-WRD project hydrologists will be jointly responsible for making specific model improvements and modifications to handle local hydrologic conditions.

Status of the Modeling Program

The model package development is well underway. Most of the components should be ready for testing in early 1979. The data management system is operational with regard to data input and storage. Data retrieval and model interface capabilities are currently being developed. When the model interface capabilities of the data system are completed, a training course on model concepts and applications will be developed and conducted for model users. This will take place in the summer of 1979.

Data collection is now underway at 20 small basin study sites. Initial estimates are that 3 to 5 years of data will be required for model calibration and verification. The actual time required will depend on the number of hydrologic events recorded and could possible exceed 5 years in the more arid regions. Verification at the end of this period will be based on model simulations of basins in a pre-mined condition. At this point, predictions could be made regarding the hydrologic impacts of surface mining by modifying selected model variables and parameters. However, full verification of these prediction capabilities will depend on the availability of data from mined and post-mined watersheds. Prediction verifications on the current study basins will be a function of the time and speed with which they are mined. Figure 4 shows a time chart depicting the tentative completion dates for various phases of the program.

The completion dates are a function of data availability and calibration success. The more humid basins will have the earliest calibration completion dates and the more arid basins will have the latest completion dates. The timetable stops at the current budget planning period (FY 81), however, the calibration, verification, and application phases of the program continue beyond FY 81.

The program is currently supported by EMRIA at an annual level of $800,000. Funding will need to be increased approximately 25% in 1980 and 1981 to complete the water quality components and to supply the driving variable data for future model application to ungaged areas.

Calibration has begun on a few watersheds in Colorado having nearly four complete years of data. One of these watersheds is currently being mined, offering an opportunity for verification of the model in the near future.

Program Phase	FISCAL YEAR 76	77	78	79	80	81
Data Collection on Study Basins	XXXXXXXX	XXXXXXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXXXXXXXXXX
Model Component Development		XXXXX	XXXXXXXXXX	XXXXXXXXX	XXXXXXXXX	XX----------→
Model Component Testing			XXXXXX	XXXXXXXXX	XXXXXXXXX	XXXXXX-------→
Model Calibration and Verification on Pre-Mined Basins				XXXXX	XXXXXXXXX	XXXXXXXXXXXXXX
Model Calibration and Verification on Mined Basins					XXXXX	XXXXXXXXXXXXXX
Progress Reports				XXX	XXX	XXX
Users Manual				XX	XXXXXXXXX-	------------→
User Training				X	X	X
Model Application						XXXXXXXXXXXXXX

-----------→ Indicates continuous updating and improvement.

FIGURE 4. Timetable showing a schedule of the modeling program.

GPO 851-523

ureau of Land Management
brary
ldg. 50, Denver Federal Center
nver, CO 80225